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~~METHOD FOR CONTROLLING A WIND-UP, INCLUDING DETERMINING RUNNING PARAMETERS BASED ON MODELS TAKING UN-WINDING INTO ACCOUNT~~

The invention relates to a method according to the preamble of claim 1.

When, in wind-ups known from prior art, the wind-ups of new slitter-winders are started up or the winding of new paper grades is started using slitter-winders already in use, the structure of the roll is controlled by so-called winding parameters, nip load, the tension of the web before the wind-up, and winding force, which, in known applications, are set, based on experience, as a function of the diameter of the roll to be so-called winding recipes. The initial guesses for the winding recipes generally originate from other slitter-winders, with which the same or a similar paper grade has been run. However, due to the great variation in the properties of paper grades having the same grade name when run in different paper machines, case-specific trial runs are always necessary in order to determine the winding recipe. Each paper grade and end diameter of a roll is usually provided with a winding recipe of its own.

In applications known from prior art the quality of the finished rolls coming from the wind-ups is primarily determined based on visual estimation. In most slitter-winders the rolls also undergo occasional measurements; most often the hardness of the roll is measured by means of a manually operated roll hardness sensor.

It is also known from prior art to provide the slitter-winders with surface density calculation and display. In these known applications the surface density value corresponding to an arbitrary roll diameter has been determined from the surface of the roll based on the change in the thickness of the paper.

Applications are known from prior art in which the object is to estimate the stresses within the roll with the help of measurements. Patent application *WO 9950719* "Verfahren und Anordnung zur neuronalen Modellierung einer Papierwickel Vorrichtung" discloses a method in which the tension of the web when it goes into a roll is determined by means of learning via neural networks. This enables the calculation, with the help of winding models, of a two-dimensional stress distribution inside the roll. Patent application *DE 19821318* "Verfahren zum Überwachen der Wickerhärte einer Wickelrolle" discloses a method for the measurement of the tension of the web when it goes into a roll, which method is based on measuring the change in the web length on the basis of coloured marks printed on the web.

A large number of the winding defects generated during winding will go unnoticed when visual estimation or measurement with a hardness sensor is used [David R. Roisum: "How to Measure Roll Quality", Tappi Journal 71(10) 1988, David R. Roisum: "Reading a roll", Tappi Journal 81(4) 1998]. Even if the two-dimensional stress distribution of the rolls could be calculated using the procedure of the patent applications WO 9950719 and DE 19821318, in most cases it would not be possible to prevent the generation of potential or actual winding damage, because the above methods do not take into account the causes of damage due to the loads directed to the roll in a paper mill slitter-winder (winder) and in the paper mill customer's finishing device.

For the paper manufacturer, however, the most important and critical feedback on the quality of the rolls comes from the customers, such as printing houses, for example in a case where running problems have occurred when the rolls have been run, for example, in a printing machine. In such a case the corrective measures in the paper manufacturing process or in the winding recipes of the slitter-winder can only be taken after a delay of several days or even weeks. If the frequency of the variations in

the properties of paper (mass, surface properties) is greater, there is no sense in taking corrective measures.

Due to the above-mentioned quality feedback delay, when starting up new slitter-winders or when starting the winding of new paper grades using slitter-winders already in use, the search for winding recipes is often slow.

A particular problem in the selection of the winding parameters of the winding recipes is that most defects cannot be noticed on the basis of visual examination and are not always discovered through surface density or equivalent measurements, and, as explained above, getting actual feedback on quality takes long.

An object of the invention is to provide a method by means of which the winding parameters can be determined so as to make sure that the roll withstands handling both in the paper mill and at the customer end.

Another object of the invention is to provide a method by means of which the problems described above are eliminated or at least minimized.

A special object of the invention is to provide a control method for controlling a wind-up, which method also takes into account the loads directed to the roll in the wind-up and in the paper mill customer's machinery.

To achieve the afore-mentioned objects and those that come out later the method according to the invention is mainly characterized in what is presented in the characterizing part of claim 1.

An essential advantage of the invention is that it is based on the idea of providing a roll which will go through its entire life span without being damaged, whereas models and

systems known from prior art aim to provide, on the wind-up, an optimal roll with respect to winding.

In the method according to the invention for controlling a wind-up, in which method a winding recipe is prepared containing winding parameters, running parameters of the wind-up are determined on the basis of calculatory and/or experimental models before the run such that, based on the models, the roll will withstand the winding up taking place in the end-use device without being damaged. According to an advantageous additional feature in the method according to the invention the running parameters of the winder are determined such that, based on the models, the roll will withstand the winding up taking place in the wind-up. According to a further advantageous additional feature in the method according to the invention the winding recipe of the roll is formed as a function of the diameter or radius or the degree of thickness of the cumulated paper on the winding core or as a function of wound web length or the number of laps of the wound web.

According to an advantageous application of the invention the internal stress distribution of the rolls is measured, the forces directed to the roll during winding are calculated by means of a load model and the relaxation of the internal stresses of the roll during transportation is estimated by means of the model and the forces directed to the roll in the paper mill customer's finishing devices are calculated by means of the load model.

According to an advantageous application of the method according to the invention:

a) the internal stress distribution of the roll being wound up is measured indirectly in three or two dimensions
b) the internal stresses caused by forces directed to the roll during winding are calculated with the help of a roll load model [Kilwa Ärölä: "A Simulation

Program for Hyperelastic Rolling Contact Model), Master of Science Thesis, Helsinki University of Technology 2001.]

c) the relaxation of the internal stresses of the finished roll, before the roll is processed in the paper mill customer's finishing device (e.g. a printing machine), is estimated and

d) the stresses and displacements directed to the roll during unwinding are calculated by means of a load model (RAMA) of the roll and the unwinding device.

The information on the paper material needed in the method according to the invention is partially obtained through off- and on-line measurements of the paper processing equipment preceding the slitter-winder and partially through measurements of the slitter-winder itself (e.g. radial and tangential modulus of elasticity).

In the method according to the invention the winding recipe is, according to an advantageous application, sought such that the stress distribution of the roll, calculated with the WOT model (WOT = Wound-On-Tension i.e. the tension of the uppermost layer on the web roll, sometimes also referred to as WIT = Wound-In-Tension) [M. Jorkama: "Contact Mechanical Model for Winding Nip". Dissertation, Helsinki University of Technology, 2001], the roll structure model and the roll relaxation model provides damage-free unwinding on the finishing device according to the RAMA model (= load model of the end-use device). In the search for the winding recipe, account has to be taken of the physical properties of the winding device and of ensuring damage-free winding and runnability on the slitter-winder, which are estimated with the load model of the wind-up. During running of the slitter-winder the recipe is being fed back on the basis of WOT measurement so that a stress distribution according to the previous step is generated in the roll.

In the roll structure measuring method it is possible to use a WOT estimated through the change in the web length measured, for example, by means of laser speed sensors.

The structure of the roll is in such a case calculated using the Hakiel model [Z. Hakiel: "Nonlinear Model for Wound Roll Stress". Tappi Journal 70(5) 1987] or an equivalent model [Zabaras N., Liu S., Koppuzha J. and Donaldson E. "A Hypoelastic Model for Computing the Stresses in Center-Wound Rolls of Magnetic Tape" Journal of Applied Mechanics, Vol 61 No. 2, pp. 290-295, 1994]. It is also possible to make use of a method utilizing the density of the roll, paper thickness and the winding model [David R. Roisum: "The Measurement of Web Stresses During Roll Winding". Dissertation WHRC at OSU 1990].

In the structure models of the slitter-winder wind-up and the finishing device, slippages generated within the roll and possibly other damage mechanisms as well are calculated. With the help of the calculated slippages the damage potential of the roll is estimated by using empirical data and roll damage models [N. Vaidyanathan and J.K. Good: "The Importance of Torque Capacity in Predicting Crepe Wrinkles and Starring within Wound Rolls". Proceedings of the 3rd IWEB conference. OSU 1995, Lee, Ban-Eop: "Buckling Analysis of Starred Roll Defects in Center Wound Rolls". Dissertation WHRC at OSU 1991.]

When estimating the relaxation of the stresses of the finished roll, known viscoelastic winding models are used, such as the reference [W. R. Qualls and J.K. Good: "A Nonlinear Orthotropic Viscoelastic Winding Model". Proceedings of the 3rd IWEB conference. OSU 1995].

The method according to the invention renders winding "intelligent" i.e. the feedback between the quality of the roll and the winding parameters, which before had taken several days or weeks, can now be carried out during the running of the slitter-winder. Reactions to changes in the paper properties and in the production conditions in the paper mill take place automatically and immediately.

By means of the method according to the invention it is possible to determine quickly the optimal winding recipes, when starting up new slitter-winders or when starting the winding of new paper grades using slitter-winders already in use.

The method according to the invention enables optimal invidual control of the winding stations, which also reduces variations in quality between the rolls of the same set.

By way of summary, in the method according to the invention, the controlling of the wind-up is based on a prediction drafted with the help of a model on the runnability of the roll in end-use, in which prediction, according to an advantageous application, a WOT vs. diameter reference curve providing optimal runnability during end-use in the finishing device is determined by iterating the model before the run. According to advantageous characteristics of the invention the running parameters of the wind-up of the slitter-winder are adjusted such that the measured WOT curve corresponds to the WOT reference curve obtained by iterating the model. The WOT reference curve may also be modified based on the runnability prediction provided by means of the winding model. When making the runnability prediction, the roll stress relaxation model is advantageously made use of and the initial estimate for the running parameters is most appropriately calculated using the winding nip model.

The invention will now be described in more detail with reference to the figures of the accompanying drawing, to the details of which the invention is, however, by no means intended to be narrowly confined.

Figure 1 schematically shows the basic principle of the method according to the invention.

Figure 2 schematically shows by means of an example a WOT curve selection procedure used in the method according to the invention.

Figure 3 schematically shows an example in the method according to the invention for establishing an initial value of a winding recipe.

Figure 4 schematically shows a subprocess of Figure 1 during the running of a slitter-winder, the slitter-winder having WOT measurement.

Figure 1 shows the basic principle of an application of the method according to the invention. The starting data 11 needed includes basic information on the paper to be wound, such as thickness, friction coefficient, elastic moduli in thickness and machine direction, information on the viscoelastic properties of the paper, air permeability and surface roughness, etc., mechanical data on the wind-up device as well as mechanical data on the end-use device of the roll or on the unwinding device on which the unwinding will take place. In step I an appropriate WOT curve 12 is selected. This selection process will be explained in more detail in the description of Figure 2. To enable the utilization of this WOT curve $WOT_{ref}(D)$ (D = roll diameter) the wind-up must incorporate a method for calculatory or measurement-based estimation of WOT. In the subsequent step II a winding recipe 13 $R_{ref}(D)$ is selected that produces, according to the winding model of the slitter-winder, step III, a WOT curve 12 $WOT_{ref}(D)$ according to step I. After this, in step IV, the load model of the winding device is used to check further that the rolls to be wound up withstand the loads 19 produced in the winding process. If the winding model indicates that the rolls withstand the loads, the process can be continued, i.e. a transition to step V is made, otherwise a new recipe is generated, i.e. there is a return to step II $R_{ref}(D)$, which new recipe provides, based on calculation, the selected WOT curve 12 $WOT_{ref}(D)$, and steps III and IV are gone through again. If, after this, there is still need to continue iteration, a new recipe can be generated, for example, by means of a so-called secant method [Erwin

Kreyszig: "Advanced Engineering Mathematics". Sixth Edition, John Wiley & Sons, Inc. 1988, p. 956], meaning that a gradient approximation in the winding parameter space is formed of the recipes of two successive iterations, the maximum stresses of the roll, for example, being the object function to be minimized. A limiting condition for the minimization task is that the winding recipe produces, in step I, a WOT curve 12 selected on the basis of calculation. Let us assume, for the sake of simplicity, that a winding recipe is established by iteration as described above which, based on calculation, a) withstands the winding process and b) gives the selected WOT curve. Were such a recipe not found, it would be necessary to return to step I and establish a new WOT curve $WOT_{ref}(D)$, etc. As stated, it is assumed here that an appropriate recipe has been found and the operation of the slitter-winder 16 can be started, i.e. a transition to step V can be made. If no WOT measurement has been performed in the wind-up or slitter-winder, the slitter-winder is run in step V with the recipe R_{ref} 13 without changing the recipe during the running. If the wind-up or slitter-winder has WOT measurement, the procedure is as follows: During the run this recipe R_{ref} selected in the preceding step is corrected so as to provide the WOT curve 12 $WOT_{ref}(D)$ according to step I. The correction of the recipe 13 is made, for example, by adjusting primarily winding force, secondarily nip load, and finally tension. Increasing each winding parameter increases WOT. The adjustment can be carried out, for example, as a simple PID controller [K. Åström & T Hägglund: "PID Controllers: Theory, Design, and Tuning". 2nd edition, 1995, pp. 59-119]. If, in the next run, the paper grade and starting data remain substantially the same, the realized winding recipe 17 according to step VI can be adopted directly as the winding recipe 13 of step II of the next run. The basic principle has been illustrated above by way of a simple example only. Further adjustments and measurements may be added to this basic frame. For example, after step IV it is possible to calculate, by means of the realized winding recipe 17, the winding model of the slitter-winder to detect possible winding defects. The end result is checked before the next run. If the calculation showed that the rolls withstand the load, no further measures are needed. If, however, the calculation suggested a

high probability of damage, iteration of an appropriate WOT curve 12 has to be started or additional limitations for the winding parameters have to be set.

Figure 2 describes the selection procedure of the WOT curve 12 in more detail by means of an example. The basic principle for the selection of the WOT curve 12 is that, based on some argument, said WOT curve 12 provides damage-free unwinding in the end-use device of the roll. The argument used can be, for example, the calculation model RAMA, step IIc, as in this example, or a statistical model or data or a combination of these. The procedure begins with selecting, in step I, an initial guess as the WOT curve $WOT_0(D)$, i.e. initialization of iteration is carried out 22 WOT_i = WOT_0 (D), where D = roll diameter. This may be, for example, a constant independent of the diameter, where the value of the constant may be 15-20 % of the tensile strength of the web. After this, in step II, step IIa, the stress distribution of the roll directly after winding is calculated with a winding model, such as the Hakiel or von Hertzen winding model. Next, the relaxation of stresses, step IIb, is estimated, by using this result as the initial value, in the time span before the roll is unwound in the end-use device. In the next step III, the stresses obtained from the relaxation model in the preceding step II are used as initial values, and the strength or runnability 24 of the roll during unwinding in the end-use device is estimated. The estimation can be based, as is the case in this example, on the calculation model of step IIc. Statistical and empirical results as well as combinations thereof may also be used. If, based on the estimation, the roll will withstand the process, this selection process of the WOT curve 26 is complete, step IV. If, based on the estimation, the roll will not withstand it, there must be a return to step I and a new candidate for a WOT curve $WOT_1(D)$ 22 has to be selected. Once again, this may be, for example, a constant independent of the diameter, the value of the constant being, for instance, 98 % or 102 % of $WOT_0(D)$. If this new WOT curve passes step III, the selection process of the WOT curve is complete, step IV. If $WOT_1(D)$ 26 does not satisfy step III, iteration has to be continued 25. A new WOT curve candidate can be formed of the two previous ones,

by using, for example, a variation of the secant method [Erwin Kreyszig: "Advanced Engineering Mathematics". Sixth Edition, John Wiley & Sons, Inc. 1988, p. 956]. This makes it possible, for instance, to minimize the stress maximum in the RAMA calculation, step IIc, among other things, in a normed space formed by continuous functions. Here, in this description of the procedure, it is assumed that the WOT curve search process produces a curve $WOT_{ref}(D)$ 26, which satisfies step III, after steps IIa, IIb and IIc, even though it could in principle happen, for example, that the value of WOT would at some point exceed the tensile strength of the web, meaning that a suitable solution would not be found.

Figure 3 shows an example of the search for the initial value 13 of the winding recipe. In step I, initialization of iteration is carried out 32 $R_j = (N,F,T)_j = R_0(D) = (N_0,F_0,T_0)(D)$, where $(N_0,F_0,T_0)(D)$ has to be realizable and R_j = winding recipe, N = nip loads, F = winding force and T = web tension. The object is to seek the winding recipe $R(D)=(N(D),F(D),T(D))$ 32 so that, when calculated with the WOT model of the wind-up (see Jorkama Dissertation, or empirical model), the winding recipe gives the WOT curve 12 selected in step I of Figure 1. Above, N(D) is nip load(s) as a function of the diameter D, F(D) winding force as a function of the diameter and T(D) web tension before the wind-up as a function of the diameter. The winding recipe generated as a result of this subprocess is marked with $R_{ref}(D)$ 36. In the function form the objective is thus to find the winding recipe such that $WOT_{ref}(D)=WOT_{model}(R_{ref}(D),D)$, where the WOT_{model} function represents the WOT model. The procedure is similar to that of other iterations based on the secant method. First, an initial guess $R_i = R_0$ is selected, step I, and a WOT curve $WOT_i=WOT_0$ is calculated, step II, with a WOT model 33 $WOT_i = WOT_{model}(R_i(D), D)$. For example, the following values can be used as the initial guess: The nip load a constant independent of the diameter for as long as possible, the winding force a constant independent of the diameter, for example, 75 % of web tension and the web tension also a constant independent of the diameter, e.g. 15-20 % of the tensile strength of the web.

If, in the checking of step III, WOT_0 is, on the basis of a chosen accuracy requirement, close enough to WOT_{ref}, a transition to step IV can be made and R_0 can be selected as the winder recipe R_{ref} 36. However, if WOT_0 is not sufficiently accurately WOT_{ref}, iteration is continued from step II by selecting a new winding recipe R_1 35. It can, for example, be selected such that the running tension is selected to be 98 % and 102 % of the running tension of R_0. If this new recipe 35 passes step III, the winding recipe selection process is complete. If R_1 does not realize step III either, iteration has to be continued. A new winding recipe candidate can be formed out of the two previous ones, e.g. using a variation of the secant method. This way, for example, the distance between $WOT_i(R_i(D),D)$ and $WOT_{ref}(D)$ can be minimized in a normed space formed by continuous vector-valued functions. A metric formed, for example, of the L^2 norm can be used as a distance function. Limitations due to the mechanics of the wind-up and to the strength of the paper have to be taken into account as a constraint to minimization.

Figure 4 presents step V running of slitter-winder 16 of Figure 1 in more detail in a case where the slitter-winder comprises WOT measurement. In short, recipe R_{ref} 42 is used to run the slitter-winder in this process. However, during the run the recipe is corrected so that the measured WOT and WOT_{ref} are joined 45. When running the slitter-winder the diameter of the roll being wound up and WOT 44 are continuously measured. The WOT measurement can be carried out, for example, according to the reference [Roisum, D., "The Measurement of Web Stresses During Roll Winding", PhD Thesis, Web Handling Research Center at Oklahoma State University., May 1990]. It is checked, at certain intervals (e.g. 5 seconds), whether the measured WOT, marked with $WOT_{measurement}$, is the same or at a set tolerance from WOT_{ref}. During the run the winding recipe Rref 46 is continuously changed so that $WOT_{measurement}$ is the same or at a set tolerance from WOT_{ref}. This adjustment can be carried out, for example, as a PID controller [K. Åström & T Hägglund: "PID Controllers: Theory, Design, and Tuning". 2nd edition, 1995. Pages 59-119]. The correction of the recipe is made,

for example, by adjusting primarily winding force, secondarily nip load, and finally tension. Increasing each winding parameter increases the WOT.

The invention has been described above with reference to one of its advantageous exemplifying embodiments only, to the details of which the invention is by no means intended to be narrowly confined.

For example, the invention is described above with reference to an example, in which, in the method, the winding recipe of the roll is formed as a function of the diameter. It is also possible to formulate the winding recipe as a function of the radius or the degree of thickness of the cumulated paper on the winding core or wound web length or the number of laps of the wound web.